

Observations on the Heart Shell, *Corculum cardissa* (L.), and Its Associated Zooxanthellae

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INTRODUCTION

THE HEART SHELL, *Corculum cardissa* (L.), has a peculiar type of shell. It is greatly compressed antero-posteriorly, resulting in a distinct heart shape, which is the source of the common name. Moreover, it has many zooxanthellae in its gill filaments, labial palps, mantles, and liver. The peculiar shape and habits of this mollusk may be explained by this association with zooxanthellae.

This is the second case of association with zooxanthellae known in the lamellibranchs. It is interesting to compare it with the other. Tridacnidae, which is fully described by Yonge (Rept. Great Barrier Reef Expedition 1928-1929. 1: 283-321, 1936).

These observations and experiments were carried out at the laboratory of the Palao Tropical Biological Station and the reef flat in its vicinity in 1936 and 1940. A preliminary report was published in 1941 in *Science of the South Sea (Kagaku Nanyo)* 3: 179-180 [in Japanese].

HABITAT

At Palao *Corculum* is found on reef flats under strong sunshine. It usually lies on the sand flat where dead shells and coral fragments have accumulated, and its anterior end faces the ground. It lies in a roughly horizontal position, excavating the bottom to the form of its shell, which is sometimes greatly produced anteriorly, as is shown in Figures 2 and 3. There is usually no attachment to the bottom but exceptionally there are several short threads of byssus.

It is very difficult to find the shell in its habitat, as the upper surface is frequently covered with filamentous algae or muddy depositions. In an active state the shell opens by 2-3 mm. at the ventral end and a vigorous current is produced from an exhalant siphon which is projected slightly at the middle of the shell. An inhalant siphon is situated ventrally and on the same level of the shell. At the ventral end of the shell the mantle is separated. Very thin, small papillae appear at the distal portion.

THE SHELL

One specimen of shell is seen in Figures 1 and 2, from the top (or posterior in anatomical point of view) and left sides, respectively. The boundary of the shell rests, usually, on a plane but it is frequently slightly convex or concave. The height is not the same from

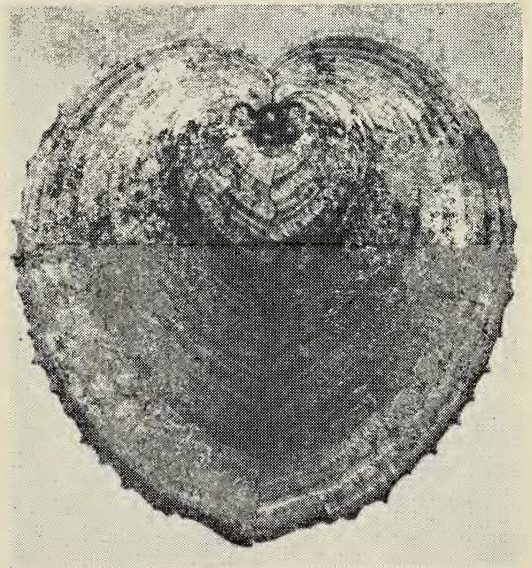


FIG. 1. Upper (posterior) surface of heart shell. (Natural size.)

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the mid-line to the posterior end as it is to the anterior end. The form of the shell is variable as is shown in Figure 3.

Side views of the shells usually display many similarities to those of *Cardium*. In some cases, however, the posterior surface is almost completely flat, with the posterior end of the shell indicated by a little projection and with somewhat of a depression at the mid-portion.

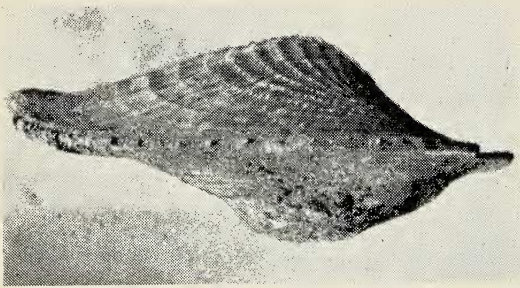


FIG. 2. Lateral view of heart shell. (Slightly reduced.)

It is frequently observed that a smaller shell has a rather elongate shape and a larger one has a more rounded shape. This relation may also be traced in one shell as is shown in Figure 4. When the shell outline is supposed as cut off at a certain growth line the remaining parts of the shell represent the form of the younger shell. In this manner, a series of shell forms is obtained such as is shown in Figure 4 *a-i*. These figures clearly show that the younger form is more elongate than the older one. This relationship is shown numerically in Table 1. The ratio of breadth

(lateral width) to height (dorso-ventral) is greater in the larger specimens.

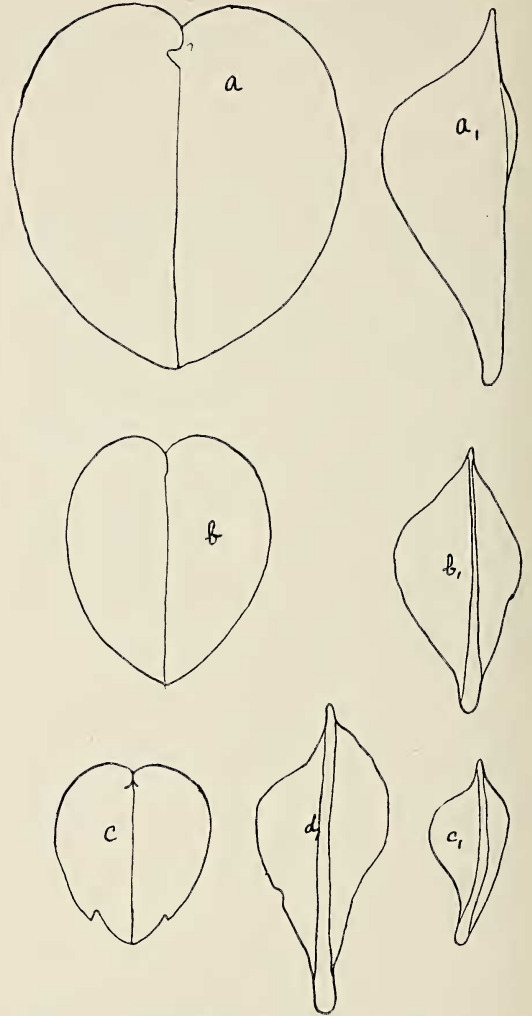


FIG. 3. Outlines of shells of *C. cardissa* showing variations in shape of shell. *a, b, c*, Posterior profile; *a₁, b₁, c₁, d₁*, lateral profile.

TABLE 1
MEASUREMENTS OF THE SHELL OF *Corculum cardissa*

LOCALITY	HEIGHT	BREADTH	LENGTH	THICKNESS	TOTAL WEIGHT	B/H*	S†	W/S‡
	<i>cm.</i>	<i>cm.</i>	<i>cm.</i>	<i>mm.</i>	<i>gm.</i>			
Palao	6.50	6.00	2.50	0.5-0.7	13.4	0.92	61.7	0.217
Palao	5.63	5.20	2.36	0.5-0.6	8.7	0.92	42	0.207
Ryukyu	4.66	3.87	2.4	0.5	6.5	0.83	24	0.270
Ryukyu	3.25	2.85	1.45	0.2-0.3	1.99	0.88	14	0.14

* B/H Ratio of breadth to height.
 † S Surface area in square centimeters.
 ‡ W/S Weight in grams per square centimeter of surface area.

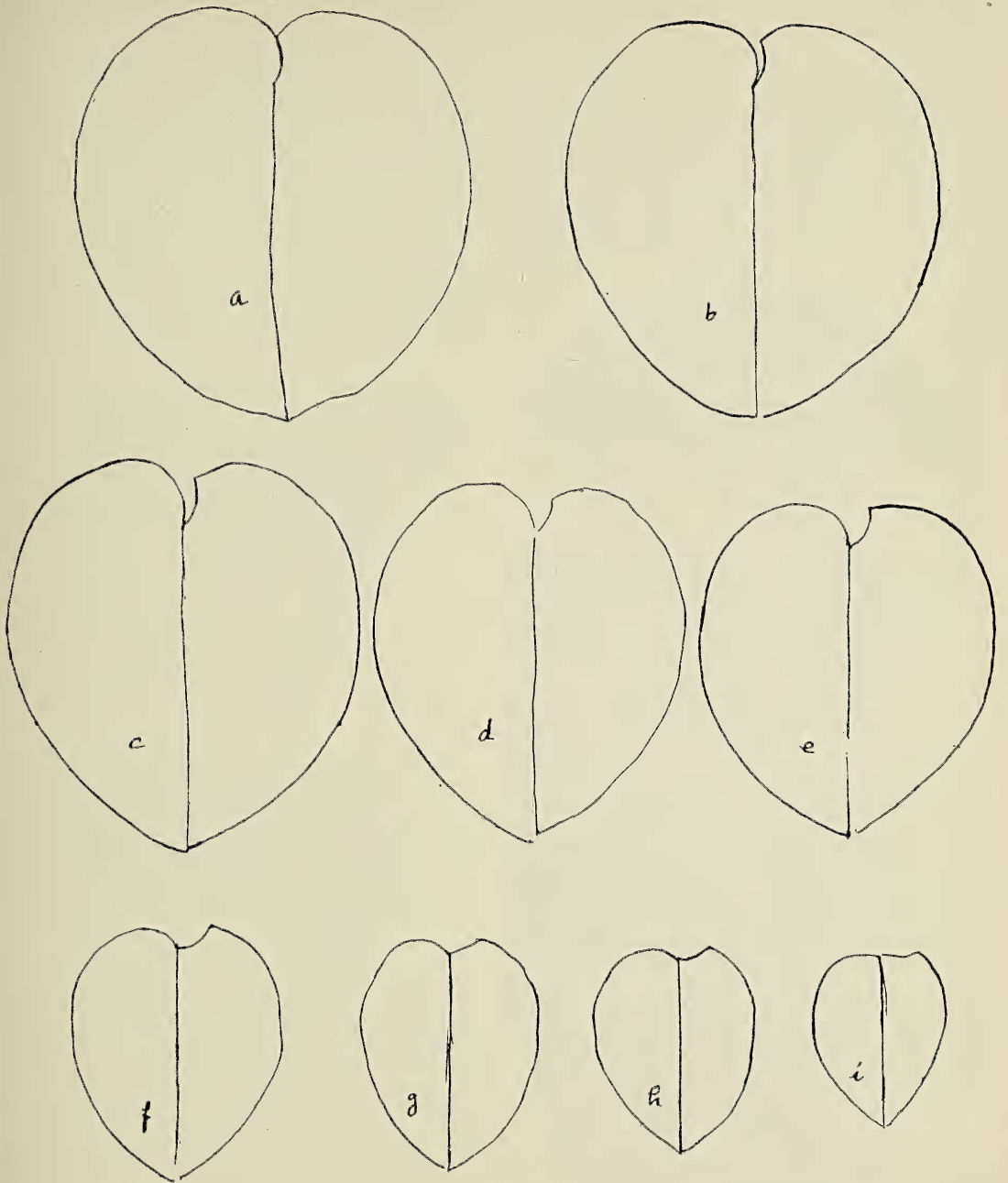


FIG. 4. Reconstruction of a series of growth forms of *C. cardissa*. (Explanation in text.)

The shell is remarkably thin, as is shown in Table 1. It is also remarkable in the uniformity of the thickness throughout the whole shell. Only at the anterior, that is, lower, side the ventral portion shows a slight thicken-

ing. In a very small specimen the shell is very thin but it rapidly attains a maximum thickness of between 0.5 and 0.7 mm. The area of cross section of shell is measured and weight of shell per unit of this area is cal-

culated in column 9. These data also bear out the same fact.

In a first glance at the shell, the lower side seems to be thicker than the upper side. But actually they are almost of the same thickness. This apparent difference is a result of the greater transparency of the upper side. On this side, there is a beautiful pattern which is shown in Figure 5. The pattern is formed by the mosaic arrangement of transparent mass and nontransparent whitish mass. On the lower side the transparent portions are scattered, rarely in rather large masses, and fade into whitish ground. Transparency of the shell is intensified if the shell is immersed in water because of elimination of reflected light from the uneven surface.



FIG. 5. Enlarged view of pattern on the shell of *Corculum*. The pattern is formed by the mosaic arrangement of transparent mass and non-transparent whitish mass.

LARVAL DEVELOPMENT

Corculum is a hermaphroditic animal. Development is indirect and it is remarkably rapid. Spawning was once observed on February 29, 1940, in the laboratory. A specimen collected on the previous day and cultured in a glass basin extruded eggs at 11 o'clock in the morning; by the end of 2 hours they had reached the two-cell stage. In the

evening they had become veligers and began to move. The next morning, all of them had grown to the two-valved stage and were swimming at the surface of the culture medium. They grew into the usual type of bivalve shells by the next evening, and settled to the bottom. Up to this time, there was no indication of the heart shape which is characteristic of this animal. There are no zooxanthellae in any tissue at this time. In what stage they attain the association with zooxanthellae is not yet known.

ASSOCIATION WITH ZOOXANTHELLAE

Gills

The normal position of the internal organs is somewhat displaced in accordance with the deformation of the shells. The organs are shown in Figures 6a and 6b. The gills and mantles are the most interesting. The gills are situated at both sides dorsally. They are short and narrow in figures, even in the photograph in the living state (Fig. 6). In the active state, however, they expand fully, just under the mantle, almost filling the whole mantle cavity. The length of the gill filaments of the inner lamella is much greater than that of the outer lamella, especially at the middle portion. This serves to fill the mantle cavity with gill filaments in the active state.

The gill is dark brown in the living animal. When it is examined under a microscope many zooxanthellae are found to be present in the filaments (Fig. 7a). The zooxanthellae do not seem to be enclosed in the host's cells.

Mantle

The mantle shows similar modifications in its structure and relative position. It forms a thin and heart-shaped mantle cavity. The mantle edges are fused at the middle of the upper side into an exhalant siphon; more ventrally they form an inhalant siphon, in the

living state, without showing morphological fusion.

The mantle of the upper side is pale and contains only a few zooxanthellae. The lower side, however, is dark brown in color due to the presence of the great accumulation of zooxanthellae. The difference is most striking at the folding line of the mantle from upper to lower surfaces as is shown in Figure 7*b*. The lower side is almost solidly dark but the upper side is only scattered with the zooxanthellae.

penetrate through the mantle as there are no more zooxanthellae beneath the mantle.

There are many pigment granules on the outer surface of the mantle. They are blue, reddish-purple, or red in color, with significant fluorescence. They are a little larger than the dimensions of zooxanthellae. Whether these pigment granules may act as a filter for too strong light is not clear.

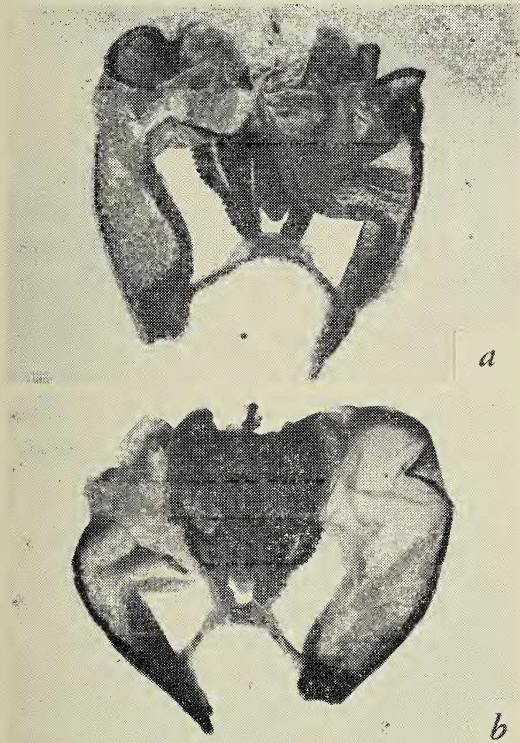


FIG. 6. *a*, *C. cardissa* with shell removed. Seen from lower side. The many dark spots are colonies of zooxanthellae. (Natural size.) *b*, Body of *C. cardissa* as seen from upper side. (Natural size.)

The mantle is extremely delicate and thin except at the edge. These relations may allow effective penetration of light to the gill filaments where the zooxanthellae are accumulated in great abundance. On the lower side, however, there is no need for the light to

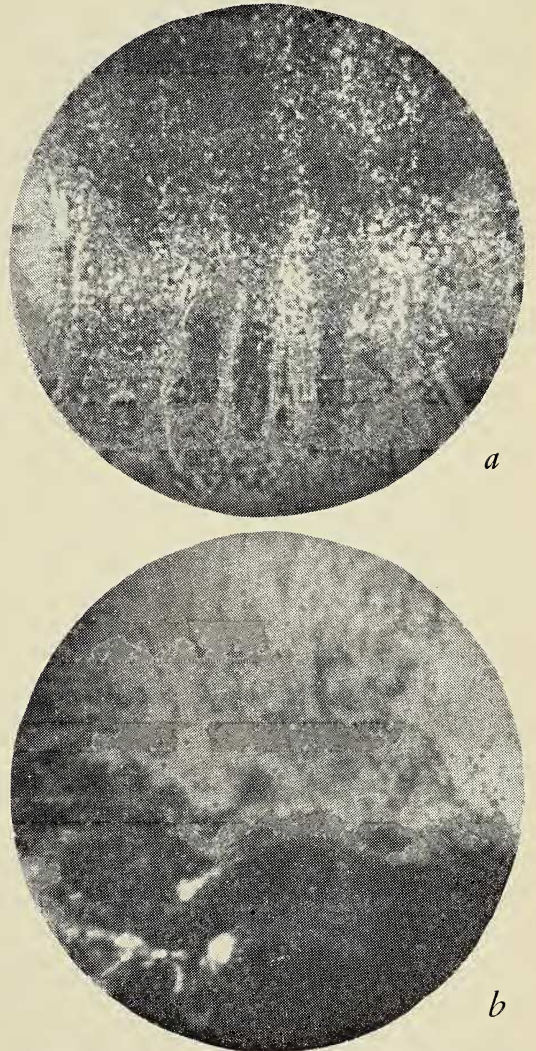


FIG. 7. *a*, Gill filaments of *Corculum* in living state, showing a full accumulation of zooxanthellae in them. A series of cilia is seen on each gill filament. *b*, A part of folding zone of mantle showing the great accumulation of zooxanthellae in the lower portion (seen evenly dark) and the lesser scattering in the upper portion.

Digestive organ

Many zooxanthellae occur in the lobes of the liver, as is shown in Figure 8. There are many grades of disintegration of zooxanthellae. From this fact one may conclude that the zooxanthellae are used as food although how they pass into the liver from gills or mantle is not clear.

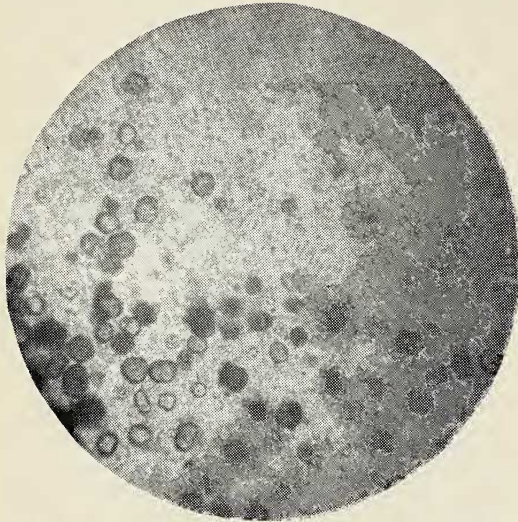


FIG. 8. Enlarged view of the content of the liver. There are many grades of disintegration of zooxanthellae in vesicles, probably phagocytic or digestive cells.

Oxygen consumption

In order to determine whether or not these symbiotic zooxanthellae have an effect on the physiology of *Corculum* the oxygen consumption in the light and in total darkness was measured. Two animals weighing about 15 grams each were placed in glass jars of about 400 cc. capacity. These were immersed in

sea water and sealed with stoppers without leaving any air bubbles in them. They were first kept in total darkness in a simple thermostat containing sea water. In the second experiment they were exposed to the sunshine in the same thermostat on the grass land of the laboratory.

Oxygen tensions of the medium were measured at the beginning and the end of the experiment by Winkler's method. An injection syringe of 5 cc. capacity was used for an analyzing vessel. Details of the results are given in Table 2.

There was marked increase of the oxygen tension in the light. These increases are certainly caused by the photosynthesis carried on by the zooxanthellae contained in the gills and mantles. The amount of increase is comparable with that shown by reef corals.

The oxygen consumption while the animals were in total darkness is in the usual range for mollusks.

COMPARISON WITH THE TRIDACNIDAE

It is very interesting to compare these observations with the data recorded for *Tridacna crocea*, in which even in the light no significant changes in oxygen exchange were observed (Yonge, loc. cit.) owing, probably, to the great bulk of tissues for the amount of zooxanthellae present.

This would indicate that there is no need of zooxanthellae for the oxygen requirements of the animal. Moreover there is a sufficient water current to remove excretory substances. One may conclude therefore that zooxanthellae may be used only for food.

TABLE 2

OXYGEN CONSUMPTION OF *Corculum* IN TOTAL DARKNESS AND IN SUNLIGHT AT 28.5°-31° C.

CONDITION	WEIGHT	DURATION OF EXPERIMENT	O ₂ INITIAL	O ₂ FINAL	TOTAL DIFFERENCE	DIFFERENCE PER HOUR PER GRAM
	<i>gm.</i>	<i>min.</i>	<i>cc.</i>	<i>cc.</i>	<i>cc.</i>	<i>cc.</i>
Dark . . .	15.8	70	4.02	3.13	-0.35	-0.019
Light . . .	15.8	40	3.90	4.84	0.37	0.035
Dark . . .	15.9	70	4.02	3.24	-0.32	-0.017
Light . . .	15.9	40	3.90	4.94	0.43	0.041

The Tridacnidae have thick, heavy shells and usually rest on the hinge and umbo. Moreover, they culture immense numbers of zooxanthellae in the mantle edge which is exposed to the sunlight. Consequently the relation of the mantle and shell to the other organs is greatly different from in *Corculum*. The Tridacnidae may be divided into two groups according to their mode of life; one is a surface living species and the other a boring species. However, they both can attain immense size of shell in tropical seas where nutritive plankton is rather rare.

Yonge (loc. cit.) considered that the presence of associated algae may enable the Tridacnidae to exceed the limits normally set to the size of a plankton-feeder and thus be

responsible for the immense size attained by *T. derasa*.

It would seem then that the presence of associated algae induces the immense size of shell in *Tridacna* but results in the thin and rather transparent shell of *Corculum*. However, the presence of the algae may not be the primary factor in the formation of the large shell in *Tridacna*, but it may have served to allow the greater development of an evolutionary tendency. That is, in the Tridacnidae it perhaps accelerated a tendency to settling into the reef with a heavy shell, whereas in *Corculum* it would seem to have accelerated a tendency toward expansion of a thin transparent shell.